

# ***Running an Application from Internal Flash Memory on the TMS320F28xxx DSP***

---

David M. Alter

Embedded Processors and Microcontrollers - Semiconductor Group

## **ABSTRACT**

Several special requirements exist for running an application from on-chip flash memory on the TMS320F28xxx DSP. These requirements generally do not manifest themselves during development in RAM since the Code Composer Studio™ (CCS) debugger can mask problems associated with initialized sections and how they are linked to memory. This application report covers the requirements needed to properly configure application software for execution from on-chip flash memory. Requirements for both DSP/BIOS™ and non-DSP/BIOS projects are presented. Some performance considerations and techniques are also discussed.

Example CCS v5 (and v4) projects are provided for the F2812, F2808, F28335, F28027, F28035, and F28069 (i.e., the superset device in each F28xxx sub-family). These can be downloaded from <http://www-s.ti.com/sc/techlit/spra958.zip>, and provide a starting point for code development irrespective of the content of this application report, if desired.

Note that the issues discussed in this application report apply to current members of the TMS320F28xxx device family, specifically:

**F281x:** F2810, F2811, F2812

**F280x/2801x/2804x:** F2801, F2802, F2806, F2808, F2809, F28015, F28016, F28044

**F2823x/2833x:** F28232, F28234, F28235, F28332, F28334, F28335

**F2802x:** F28020, F28021, F28022, F28023, F28026, F28027, F280200

**F2803x:** F28030, F28031, F28032, F28033, F28034, F28035

**F2806x:** F28062, F28063, F28064, F28065, F28066, F28067, F28068, F28069

Applicability to future F28xxx devices, although likely, is not guaranteed. Further, the code and methods presented in this application report apply to the development tool versions utilized, specifically:

CCS v5.1.0, Code Generation Tools v6.0.2, DSP/BIOS v5.41.11.38

Be aware that future tool versions may have differences that make some of the items discussed here unnecessary, although in all likelihood backwards compatibility will be maintained, so that the techniques discussed here should still work.

Finally, this application report does not provide a tutorial on writing and building code for the F28xxx. It is assumed that the reader already has at least the main framework of their application running from RAM. This report only identifies the special items that must be considered when moving the application into on-chip flash memory.

## Contents

<b>1</b>	<b>Introduction .....</b>	<b>3</b>
<b>2</b>	<b>Creating a User Linker Command File .....</b>	<b>3</b>
2.1	Non-DSP/BIOS Projects.....	3
2.2	DSP/BIOS Projects.....	4
<b>3</b>	<b>Where to Link the Sections .....</b>	<b>5</b>
3.1	Non-DSP/BIOS Projects.....	6
3.2	DSP/BIOS Projects.....	7
<b>4</b>	<b>Copying Sections from Flash to RAM .....</b>	<b>9</b>
4.1	Copying the Interrupt Vectors (non-DSP/BIOS projects only) .....	9
4.2	Copying the .hwi_vec Section (DSP/BIOS projects only).....	10
4.3	Copying the .trcdata Section (DSP/BIOS projects only).....	11
4.4	Initializing the Flash Control Registers (DSP/BIOS and non-DSP/BIOS projects) .....	12
4.5	Maximizing Performance by Executing Time-critical Functions from RAM .....	14
4.6	Maximizing Performance by Linking Critical Global Constants to RAM .....	15
4.6.1	Method 1: Running All Constant Arrays from RAM .....	15
4.6.2	Method 2: Running a Specific Constant Array from RAM.....	18
<b>5</b>	<b>Programming the Code Security Module Passwords.....</b>	<b>20</b>
<b>6</b>	<b>Executing Your Code from Flash after a DSP Reset.....</b>	<b>24</b>
<b>7</b>	<b>Disabling the Watchdog Timer During C-Environment Boot .....</b>	<b>27</b>
<b>8</b>	<b>C-Code Examples.....</b>	<b>29</b>
8.1	General Overview.....	29
8.2	Directory Structure .....	31
8.3	Additional Information.....	32
	<b>References.....</b>	<b>36</b>
	<b>Revision History.....</b>	<b>37</b>

## Figures

<b>Figure 1.</b>	<b>Specifying the User Init Function in the DSP/BIOS Configuration tool .....</b>	<b>11</b>
<b>Figure 2.</b>	<b>Specifying the Link Order In Code Composer Studio v5.....</b>	<b>17</b>
<b>Figure 3.</b>	<b>DSP/BIOS MEM Properties for CSM Password Locations .....</b>	<b>22</b>
<b>Figure 4.</b>	<b>DSP/BIOS MEM Properties for CSM Reserved Locations .....</b>	<b>23</b>
<b>Figure 5.</b>	<b>DSP/BIOS MEM Properties for Jump to Flash Entry Point.....</b>	<b>25</b>

## Tables

<b>Table 1.</b>	<b>Section Linking in Non-DSP/BIOS Projects (Large memory model) .....</b>	<b>6</b>
<b>Table 2.</b>	<b>Section Linking In DSP/BIOS Projects (Large Memory Model).....</b>	<b>7</b>
<b>Table 3.</b>	<b>CCS Example Code Directory Descriptions.....</b>	<b>32</b>

## 1 Introduction

The TMS320F28xxx DSP family has been designed for standalone operation in embedded controller applications. The on-chip flash usually eliminates the need for external non-volatile memory and a host processor from which to bootload. Configuring an application to run from flash memory is a relatively easy matter provided that one follows a few simple steps. This report covers the major concerns and steps needed to properly configure application software for execution from internal flash memory. Requirements for both DSP/BIOS and non-DSP/BIOS projects are presented. Some performance considerations and techniques are also discussed.

Example CCS v5 (and v4) projects are provided for the F2812, F2808, F28335, F28027, F28035, and F28069 (i.e., the superset device in each F28xxx sub-family). These can be downloaded from <http://www-s.ti.com/sc/techlit/spra958.zip>, and provide a starting point for code development irrespective of the content of this application report, if desired.

Note that the issues discussed in this application report apply to current members of the TMS320F28xxx device family, specifically:

**F281x:** F2810, F2811, F2812

**F280x/2801x/2804x:** F2801, F2802, F2806, F2808, F2809, F28015, F28016, F28044

**F2823x/2833x:** F28232, F28234, F28235, F28332, F28334, F28335

**F2802x:** F28020, F28021, F28022, F28023, F28026, F28027, F280200

**F2803x:** F28030, F28031, F28032, F28033, F28034, F28035

**F2806x:** F28062, F28063, F28064, F28065, F28066, F28067, F28068, F28069

Applicability to future F28xxx devices, although likely, is not guaranteed. Further, the code and methods presented in this application report apply to the development tool versions utilized, specifically:

CCS v5.1.0, Code Generation Tools v6.0.2, DSP/BIOS v5.41.11.38

Be aware that future tool versions may have differences that make some of the items discussed here unnecessary, although in all likelihood backwards compatibility will be maintained, so that the techniques discussed here should still work.

Finally, this application report does not provide a tutorial on writing and building code for the F28xxx. It is assumed that the reader already has at least the main framework of their application running from RAM. This report only identifies the special items that must be considered when moving the application into on-chip flash memory.

## 2 Creating a User Linker Command File

### 2.1 Non-DSP/BIOS Projects

In non-DSP/BIOS applications, the user linker command file will be where most memory is defined, and where the linking of most sections is specified. The format of this file is no different than the linker command file you are currently using to run your application from RAM. The difference will be in where you link the sections (to be discussed in Section 3). More information on linker command files can be found in reference [15]. The non-DSP/BIOS code projects that accompany this application report contain linker command files that can be used for reference.

The peripheral header files (see references [23-29]) contain linker command files named

DSP281x_Headers_nonBIOS.cmd	DSP2802x_Headers_nonBIOS.cmd
DSP280x_Headers_nonBIOS.cmd	DSP2803x_Headers_nonBIOS.cmd
DSP2804x_Headers_nonBIOS.cmd	F2806x_Headers_nonBIOS.cmd
DSP2833x_Headers_nonBIOS.cmd	

These files contain linker MEMORY and SECTIONS declarations for linking the peripheral register structures. Since CCS supports having more than one linker command file in a project, all one needs to do is add the appropriate one of these linker command files to your code project in addition to your user linker command file.

In general, the order of the linker command files is unimportant since during a project build, CCS evaluates the MEMORY section of every linker command file before evaluating the SECTIONS section of any linker command file. This ensures that all memories are defined before linking any sections to those memories. However, advanced users may need manual control over the order of linker command file evaluation in some rare situations. This can be specified within CCS v4 on the Project → Properties menu, CCS Build window, Link Order tab.

## 2.2 DSP/BIOS Projects

The DSP/BIOS configuration tool generates a linker command file that specifies how to link all DSP/BIOS generated sections, and by default all C-compiler generated sections. When running your application from RAM, this linker command file may be the only one in use. However, when executing from flash memory, there will likely be a need to generate and link one or more user defined sections. In particular, any code that configures the on-chip flash control registers (e.g. flash wait-states) cannot execute from flash. In addition, one may want to run certain time critical functions from RAM (instead of flash) to maximize performance. A user linker command file must be created to handle these user defined sections.

Beyond the user and DSP/BIOS generated linker command files, the peripheral header files (see references [23-29]) contain linker command files named

DSP281x_Headers_BIOS.cmd	DSP2802x_Headers_BIOS.cmd
DSP280x_Headers_BIOS.cmd	DSP2803x_Headers_BIOS.cmd
DSP2804x_Headers_BIOS.cmd	F2806x_Headers_BIOS.cmd
DSP2833x_Headers_BIOS.cmd	

These file contains linker MEMORY and SECTIONS declarations for linking the peripheral register structures. Since CCS supports having more than one linker command file in a project, all one needs to do is add all three linker command files to their project.

In general, the order of the linker command files is unimportant since during a project build, CCS evaluates the MEMORY section of every linker command file before evaluating the SECTIONS section of any linker command file. This ensures that all memories are defined before linking any sections to those memories. However, advanced users may need manual control over the order of linker command file evaluation in some rare situations (for example, to preempt and override DSP/BIOS linkage of a section). This can be specified within CCS v5 on the Project → Properties menu, then select the Build category, Link Order tab.

### 3 Where to Link the Sections

Two basic section types exist: initialized, and uninitialized. Initialized sections must contain valid values at device power-up. For example, code and constants are found in initialized sections. When designing a stand-alone embedded system with the F28xxx DSP (e.g., no emulator or debugger in use, no host processor present to perform bootloading), all initialized sections must be linked to non-volatile memory (e.g., on-chip flash). An uninitialized section does not contain valid values at device power-up. For example, variables are found in uninitialized sections. Code will write values to the variable locations during code execution. Therefore, uninitialized sections must be linked to volatile memory (e.g., RAM).

It is suggested that the `-w` linker option be invoked (it is selected by default for all newly created CCS projects). The `-w` option will produce a warning if the linker encounters any sections in your project that have not been explicitly specified for linking in a linker command file. When the linker encounters an unspecified section, it uses a default allocation algorithm to link the section into memory (it will link the section to the first defined memory with enough available free space). This is almost always risky, and can lead to unreliable and unpredictable code behavior. The `-w` option will identify any unspecified sections (e.g., those accidentally forgotten by the user) so that the user can make the necessary addition to the appropriate linker command file. In CCS v5, the `-w` option checkbox is found on the Project → Properties menu, then select the Build → C2000 Linker → Diagnostics category.

#### CAUTION:

It is important that the large memory model be used with the C-compiler (as opposed to the small memory model). Small memory model requires certain initialized sections to be linked to non-volatile memory in the lower 64Kw of addressable space. However, no flash memory is present in this region on any F28xxx devices, and this will likely be true for future F28xxx devices as well. Therefore, large memory model should be used. For CCS v5 projects, the large memory model checkbox is found on the Project → Properties menu, then select Build → C2000 Compiler → Basic Options category. It is selected by default for all newly created CCS projects.

For non-DSP/BIOS projects, one should include the large memory model C-compiler runtime support library into their code project. For the fixed-point devices, this is library *rts2800\_ml.lib* (as opposed to *rts2800.lib*, which is for the small memory model). For the floating-point devices, this is file *rts2800\_fpu32.lib* for plain C code, or *rts2800\_fpu32\_eh.lib* for C++ code (there are no small memory model libraries for the floating-point devices). In CCS v5, there is an “Automatic” setting for the library that can be used if desired to have CCS select the correct library for you based on your project settings (e.g., floating point support and memory model selections).

For DSP/BIOS projects, DSP/BIOS will take care of including the required library. The user should not include any runtime support library in a DSP/BIOS project.

### 3.1 Non-DSP/BIOS Projects

The compiler uses a number of specific sections. These sections are the same whether you are running from RAM or flash. However, when running a program from flash, all initialized sections must be linked to non-volatile memory, whereas all uninitialized sections must be linked to volatile memory. Table 1 shows where to link each compiler generated section on the F28xxx DSP. Information on the function of each section can be found in reference [8]. Any user created initialized section should be linked to flash (e.g., those sections created using the CODE\_SECTION compiler pragma), whereas any user created uninitialized sections should be linked to RAM (e.g., those sections created using the DATA\_SECTION compiler pragma).

**Table 1. Section Linking in Non-DSP/BIOS Projects (Large memory model)**

Section Name	Where to Link
.cinit	Flash
.cio	RAM
.const	Flash
.econst	Flash
.pinit	Flash
.switch	Flash
.text	Flash
.bss	RAM
.ebss	RAM
.stack	Lower 64Kw RAM
.sysmem	RAM
.esysmem	RAM
.reset	RAM <sup>1</sup>

**Table 1 Notes:**

<sup>1</sup> The `.reset` section contains nothing more than a 32-bit interrupt vector that points to the C-compiler boot function in the runtime support library (the `_c_int00` routine). It is almost never used. Instead, the user typically creates their own branch instruction to point to the starting point of the code (see Sections 6 and 7). When not in use, the `.reset` section should be omitted from the code build by using a DSECT modifier in the linker command file. For example:

```

/*****
* User's linker command file
*****/

SECTIONS
{
    .reset      : > FLASH,    PAGE = 0, TYPE = DSECT
}

```

## 3.2 DSP/BIOS Projects

The memory section manager in the DSP/BIOS configuration tool allows one to specify where to link the various DSP/BIOS and C-compiler generated sections. Table 2 indicates where the sections shown on each tab of the memory section manager should be linked (i.e., RAM or FLASH). Note that this information has been tabulated specifically for the DSP/BIOS versions used in this report (see Section 1). Later versions of DSP/BIOS, although quite likely to be the same, may have some differences. The reader should check the version they are using and simply be aware of potential differences while proceeding. In CCS v5, the DSP/BIOS version is tied to each individual project. Go to the Project → Properties menu, then select the General category.

**Table 2. Section Linking In DSP/BIOS Projects (Large Memory Model)**

Memory Section Manager TAB	Section Name	Where to Link
General	Segment for DSP/BIOS Objects	RAM
	Segment for malloc()/free()	RAM
BIOS Data	Argument Buffer Section (.args)	RAM
	Stack Section (.stack)	Lower 64Kw RAM
	DSP/BIOS Init Tables (.gblinit)	Flash
	TRC Initial Values (.trcdata)	RAM <sup>1</sup>
	DSP/BIOS Kernel State (.sysdata)	RAM
	DSP/BIOS Conf Sections (*.obj)	RAM
BIOS Code	BIOS Code Section (.bios)	Flash
	Startup Code Section (.sysinit)	Flash
	Function Stub Memory (.hwi)	Flash
	Interrupt Service Table Memory (.hwi_vec)	PIEVECT RAM <sup>2</sup>
	RTDX Text Segment (.rtdx_text)	Flash
Compiler Sections	Text Section (.text)	Flash
	Switch Jump Tables (.switch)	Flash
	C Variables Section (.bss)	RAM
	C Variables Section (.ebss)	RAM
	Data Initialization Section (.cinit)	Flash
	C Function Initialization Table (.pinit)	Flash
	Constant Section (.econst)	Flash

	Constant Section (.const)	Flash
	Data Section (.data)	Flash
	Data Section (.cio)	RAM
Load Address	Load Address - BIOS Code Section (.bios)	Flash <sup>3</sup>
	Load Address - Startup Code Section (.sysinit)	Flash <sup>3</sup>
	Load Address - DSP/BIOS Init Tables (.gblinit)	Flash <sup>3</sup>
	Load Address - TRC Initial Value (.trcdata)	Flash <sup>1</sup>
	Load Address - Text Section (.text)	Flash <sup>3</sup>
	Load Address - Switch Jump Tables (.switch)	Flash <sup>3</sup>
	Load Address - Data Initialization Section (.cinit)	Flash <sup>3</sup>
	Load Address - C Function Initialization Table (.pinit)	Flash <sup>3</sup>
	Load Address - Constant Section (.econst)	Flash <sup>3</sup>
	Load Address - Constant Section (.const)	Flash <sup>3</sup>
	Load Address - Data Section (.data)	Flash <sup>3</sup>
	Load Address - Function Stub Memory (.hwi)	Flash <sup>3</sup>
	Load Address - Interrupt Service Table Memory (.hwi_vec)	Flash <sup>2</sup>
	Load Address - RTDX Text Segment (.rtdx_text)	Flash <sup>3</sup>

**Table 2 Notes:**

<sup>1</sup> The *.trcdata* section must be copied by the user from its load address (specified on the Load\_Address tab) to its run address (specified on the BIOS\_Data tab) at runtime. See Section 4.3 for details on performing this copy.

<sup>2</sup> The PIEVECT RAM is a specific block of RAM associated with the Peripheral Interrupt Expansion (PIE) peripheral. On current F28xxx devices, the PIE RAM is a 256x16 block starting at address 0x000D00 in data space. For other devices, confirm the address in the device datasheet. The memory section manager in the DSP/BIOS configuration tool should already have a pre-defined memory named PIEVECT. The *.hwi\_vec* section must be copied by the user from its load address (specified on the memory section manager Load\_Address Tab) to its run address (specified on the memory section manager BIOS\_Code Tab) at runtime. See Section 4.2 for details on performing this copy.

<sup>3</sup> The specific flash memory selected as the load address for this section should be the same flash memory selected previously as the run address for the section (e.g., on the BIOS Data, BIOS Code, or Compiler Sections tab).



## 4 Copying Sections from Flash to RAM

### 4.1 Copying the Interrupt Vectors (non-DSP/BIOS projects only)

The Peripheral Interrupt Expansion (PIE) module manages interrupt requests on F28xxx devices. At power-up, all interrupt vectors must be located in non-volatile memory (i.e., flash), but copied to the PIEVECT RAM as part of the device initialization procedure in your code. The PIEVECT RAM is a specific block of RAM, which on current F28xxx devices is a 256x16 block starting at address 0x000D00 in data space.

Several approaches exist for linking the interrupt vectors to flash and then copying them to the PIEVECT RAM at runtime. One approach is to create a constant C-structure of function pointers that contains all 128 32-bit vectors. If using the peripheral header file structures (see references [23-29]), such a structure, called *PieVectTableInit*, has already been created in the corresponding file *DSP28xxx\_PieVect.c*. Since this structure is declared using the `const` type qualifier, it will be placed in the `.econst` section by the compiler. One simply needs to copy this structure to the PIEVECT RAM at runtime. The C-compiler runtime support library contains a memory copy function called *memcpy()* that can be used to perform the copy task as follows:

```

/*****
 * User's C-source file
 *****/

/*****
 * NOTE: This function assumes use of the Peripheral Header File
 * structures (see References [23-29]).
 *****/

#include <string.h>

void main(void)
{
    /*** Initialize the PIE_RAM ***/
    PieCtrlRegs.PIECTRL.bit.ENPIE = 0; // Disable the PIE
    asm(" EALLOW"); // Enable EALLOW protected register access
    memcpy((void *)0x000D00, &PieVectTableInit, 256);
    asm(" EDIS"); // Disable EALLOW protected register access
}

```

Note that the copy length is 256 because *memcpy()* copies 16-bit words.

The above example uses a hard coded address for the start of the PIE RAM, specifically 0x000D00. If this is objectionable (as hard coded addresses are not good programming practice), one can use a `DATA_SECTION` pragma to create an uninitialized dummy variable, and link this variable to the PIE RAM. The name of the dummy variable can then be used in place of the hard coded address. For example, when using any of the '28xxx device peripheral structures, an uninitialized structure called *PieVectTable* is created and linked over the PIEVECT RAM. The *memcpy()* instruction in the previous example can be replaced by:

```
memcpy(&PieVectTable, &PieVectTableInit, 256);
```

Lastly, on some devices, specifically the ‘Piccolo’ devices (F2802x, F2803x, F2806x), the first three 32-bit vector locations are used for bootmode selection when the debugger is in use. Therefore, the code should be modified to avoid overwriting these locations as follows:

```
Memcpy((void *)0x000D06, (Uint16 *)&PieVectTableInit+6, 256-6);
```

or

```
memcpy((Uint16 *)&PieVectTable+6, (Uint16 *)&PieVectTableInit+6, 256-6);
```

## 4.2 Copying the .hwi\_vec Section (DSP/BIOS projects only)

The DSP/BIOS *.hwi\_vec* section contains the interrupt vectors, and must be loaded to flash but run from RAM. The user is responsible for copying this section from its load address to its run address. This is typically done in *main()*. The DSP/BIOS configuration tool generates global symbols that can be accessed by code in order to determine the load address, run address, and length of the *.hwi\_vec* section. These symbol names are:

<code>hwi_vec_loadstart</code>	<code>hwi_vec_loadend</code>
<code>hwi_vec_loadsize</code>	<code>hwi_vec_runstart</code>

Each symbol is self-explanatory from its name. Note that the symbols are not pointers, but rather symbolically reference the 16-bit data value found at the corresponding location (i.e., start or end) of the section. The C-compiler runtime support library contains a memory copy function called *memcpy()* that can be used to perform the copy task. A C-code example of how to use this function to perform the section copy follows.

```

/*****
* User's C-source file
*****/

#include <string.h>

extern unsigned int hwi_vec_loadstart;
extern unsigned int hwi_vec_loadsize;
extern unsigned int hwi_vec_runstart;

void main(void)
{
  /*** Initialize the .hwi_vec section ***/
  asm(" EALLOW"); /* Enable EALLOW protected register access */
  memcpy(&hwi_vec_runstart, &hwi_vec_loadstart, (Uint32)&hwi_vec_loadsize);
  asm(" EDIS"); /* Disable EALLOW protected register access */
}

```

Lastly, on some devices, specifically the ‘Piccolo’ devices (F2802x, F2803x, F2806x), the first three 32-bit vector locations are used for bootmode selection when the debugger is in use. Therefore, the code should be modified to avoid overwriting these locations as follows:

```
memcpy(&hwi_vec_runstart+6, &hwi_vec_loadstart+6,
      (Uint32)(&hwi_vec_loadsize-(Uint16 *)6));
```

### 4.3 Copying the .trcdata Section (DSP/BIOS projects only)

The DSP/BIOS *.trcdata* sections must be loaded to flash, but run from RAM. The user is responsible for copying this section from its load address to its run address. However, unlike the *.hwi\_vec* section, the copying of *.trcdata* must be performed prior to *main()*. This is because DSP/BIOS modifies the contents of *.trcdata* during DSP/BIOS initialization (which also occurs prior to *main()*).

The DSP/BIOS configuration tool provides for a user initialization function which can be utilized to perform the *.trcdata* section copy prior to both *main()* and DSP/BIOS initialization. This can be found in the CCS v5 project configuration file under System → Global Settings Properties, as shown in Figure 1.

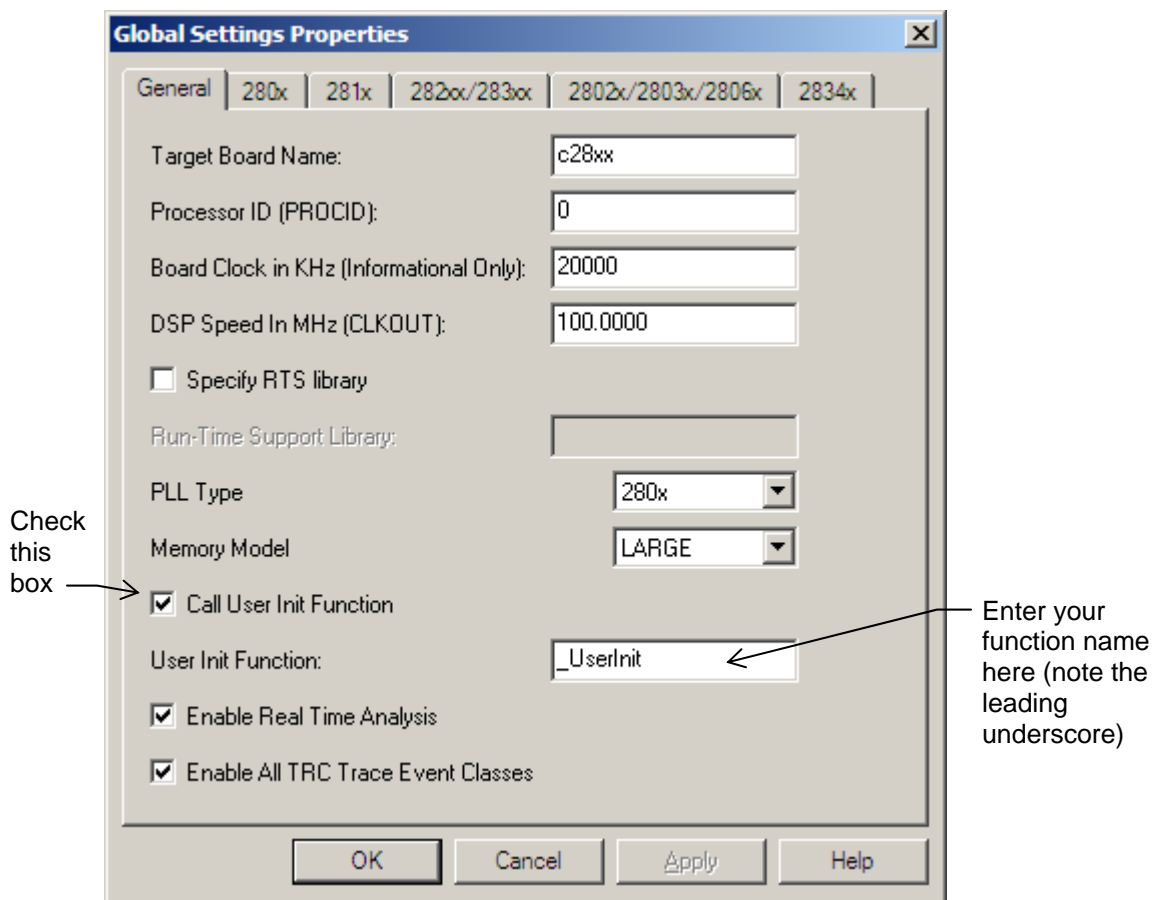


Figure 1. Specifying the User Init Function in the DSP/BIOS Configuration tool

What remains is to create the user initialization function. The DSP/BIOS configuration tool generates global symbols that can be accessed by code in order to determine the load address, run address, and length of each section. These symbol names are:

trcdata_loadstart	trcdata_loadend
trcdata_loadsize	trcdata_runstart

Each symbol is self-explanatory from its name. Note that the symbols are not pointers, but rather symbolically reference the 16-bit data value found at the corresponding location (i.e., start or end) of the section. The C-compiler runtime support library contains a memory copy function called *memcpy()* that can be used to perform the copy task. A C-code example of a user init function that performs the *.trcdata* section copy follows.

```

/*****
* User's C-source file
*****/

#include <string.h>

extern unsigned int trcdata_loadstart;
extern unsigned int trcdata_loadsize;
extern unsigned int trcdata_runstart;

void UserInit(void)
{
    /*** Initialize the .trcdata section before main() ***/
    memcpy(&trcdata_runstart, &trcdata_loadstart, (Uint32)&trcdata_loadsize);
}

```

#### 4.4 Initializing the Flash Control Registers (DSP/BIOS and non-DSP/BIOS projects)

The initialization code for the flash control registers cannot be executed from the flash memory or unpredictable results may occur. Therefore, the initialization function for the flash control registers must be copied from flash (its load address) to RAM (its run address) at runtime.

##### CAUTION:

**The flash control registers are protected by the Code Security Module (CSM). If the CSM is secured, you must run the flash register initialization code from CSM secured RAM (see the memory map in the data sheet for your specific device to identify these memories) or the initialization code will be unable to access the flash registers. Note that the CSM is always secured at device reset, although the ROM bootloader will unlock it if you are using dummy passwords of 0xFFFF.**

The `CODE_SECTION` pragma of the C compiler can be used to create a separately linkable section for the flash initialization function. For example, suppose the flash register configuration is to be performed in the C function *InitFlash()*, and it is desired to place this function into a linkable section called *secureRamFuncs*. The following C-code example shows proper use of the `CODE_SECTION` pragma along with an example configuration of the flash registers:

```

/*****
* User's C-source file
*****/

/*****
* NOTE: The InitFlash() function shown here is just an example of an
* initialization for the flash control registers. Consult the device
* datasheet for production wait state values and any other relevant
* information. Wait-states shown here are specific to current F280x
* devices operating at 100 MHz.
* NOTE: This function assumes use of the Peripheral Header File
* structures (see References [23-29]).
*****/

#pragma CODE_SECTION(InitFlash, "secureRamFuncs")
void InitFlash(void)
{
    asm(" EALLOW");                // Enable EALLOW protected register access
    FlashRegs.FPWR.bit.PWR = 3;    // Flash set to active mode
    FlashRegs.FSTATUS.bit.V3STAT = 1; // Clear the V3STAT bit
    FlashRegs.FSTDBYWAIT.bit.STDBYWAIT = 0x01FF; // Sleep to standby cycles
    FlashRegs.FACTIVEWAIT.bit.ACTIVEWAIT = 0x01FF; // Standby to active cycles
    FlashRegs.FBANKWAIT.bit.RANDWAIT = 3; // F280x Random access wait states
    FlashRegs.FBANKWAIT.bit.PAGEWAIT = 3; // F280x Paged access wait states
    FlashRegs.FOTPWAIT.bit.OTPWAIT = 5; // F280x OTP wait states
    FlashRegs.FOPT.bit.ENPIPE = 1; // Enable the flash pipeline
    asm(" EDIS");                // Disable EALLOW protected register access

    /*** Force a complete pipeline flush to ensure that the write to the last register
    configured occurs before returning. Safest thing is to wait 8 full cycles. ***/

    asm(" RPT #6 || NOP");        // Takes 8 cycles to execute
} //end of InitFlash()

```

The section `secureRamFuncs` can then be linked using the user linker command file. This section will require separate load and run addresses. Further, it is desired to have the linker generate some global symbols that can be used to determine the load address, run address, and length of the section. This information is needed to perform the copy from the sections load address to its run address. The user linker command file would appear as follows:

```

/*****
* User's linker command file
*****/

SECTIONS
{
    /*** User Defined Sections ***/
    secureRamFuncs:    LOAD = FLASH,          PAGE = 0
                      RUN  = SECURE_RAM,     PAGE = 0
                      LOAD_START(_secureRamFuncs_loadstart),
                      LOAD_SIZE(_secureRamFuncs_loadsize),
                      RUN_START(_secureRamFuncs_runstart)
}

```

In this example, the memories FLASH and SECURE\_RAM are assumed to have been defined either in the MEMORY section of the user linker command file (for non-DSP/BIOS projects) or in the memory section manager of the DSP/BIOS configuration tool (for DSP/BIOS projects). The PAGE designation for these memories should match that of the memory definition. The above example assumes both memories have been declared on PAGE 0 (program memory space). The LOAD\_START, LOAD\_SIZE, and RUN\_START directives will generate global symbols with the specified names for the corresponding addresses. Note the use of the leading underscore on the global symbol definitions (e.g., `_secureRamFuncs_runstart`)

Finally, the section must be copied from flash to RAM at runtime. As in Sections 4.1 - 4.3, the function `memcpy()` from the compiler runtime support library can be used.

```

/*****
* User's C-source file
*****/

#include <string.h>

extern unsigned int secureRamFuncs_loadstart;
extern unsigned int secureRamFuncs_loadsize;
extern unsigned int secureRamFuncs_runstart;

void main(void)
{
/* Copy the secureRamFuncs section */
    memcpy(&secureRamFuncs_runstart,
           &secureRamFuncs_loadstart,
           (Uint32)&secureRamFuncs_loadsize);

/* Initialize the on-chip flash registers */
    InitFlash();
}

```

## 4.5 Maximizing Performance by Executing Time-critical Functions from RAM

### (DSP/BIOS and non-DSP/BIOS projects)

The on-chip RAM memory on current F28xxx devices provides code execution in MIPS (millions of instructions per second) that is equal to the operating clock frequency of the device in MHz (e.g., 150 MIPS at 150 MHz, 100 MIPS at 100 MHz, etc.). However, the on-chip flash memory gives effective code execution performance that is somewhat less, depending on the device frequency and the application. Rough flash execution performance estimates for the devices covered in this application report are:

90 - 95 MIPS at 150 MHz  
 80 - 85 MIPS at 100 MHz  
 65 - 70 MIPS at 80 MHz  
 50 - 55 MIPS at 60 MHz  
 37 - 39 MIPS at 40 MHz

It may therefore be desirable to run certain time-critical or computationally demanding routines from on-chip RAM, especially for devices running at 150 MHz. In a standalone embedded

system however, all code must initially reside in non-volatile memory. Separate load and run addresses must be setup for those functions running from RAM, and a copy must be performed to move them from on-chip flash to the RAM at runtime. To do this, apply the same procedure previously described in Section 4.4.

Using the `CODE_SECTION` pragma, one can add multiple functions to the same linkable section. The entire section can then be assigned to run from a particular RAM block, and the user can copy the entire section to RAM all at once, as discussed in Section 4.4. If finer linking granularity is required, separate section names can be created for each function.

## **4.6 Maximizing Performance by Linking Critical Global Constants to RAM**

### **(DSP/BIOS and non-DSP/BIOS projects)**

Constants are those data structures declared using the C language *const* type modifier. The compiler places all constants in the `.econst` section (large memory model assumed). While special pipelining on current F28xxx devices accelerates effective flash performance for code execution, accessing data constants located in the on-chip FLASH can take multiple cycles per access. Typical flash wait-states will be 5 cycles at 150 MHz, 3 cycles at 100 MHz, 2 cycles at 80 or 60 MHz, and 1 cycle at 40 MHz device (see the specific device datasheet for flash wait-state specifications). It may therefore be desirable to keep heavily accessed constants and constant tables in on-chip RAM. However, a standalone embedded system requires that all initialized data (e.g., constants) initially reside in non-volatile memory. Therefore, separate load and run addresses must be setup for those constants you wish to access in RAM, and a copy must be performed to move them from the on-chip flash to the RAM at runtime. Two different approaches for accomplishing this will be presented.

### **4.6.1 Method 1: Running All Constant Arrays from RAM**

This approach involves specifying separate load and run addresses for the entire `.econst` section. The advantage of this approach is ease of use, while the disadvantage is excessive RAM usage (there may be only a few constants that require high-speed access, but with this method all constants are relocated into RAM).

#### **4.6.1.1 Non-DSP/BIOS Projects**

The same approach discussed in Section 4.4 can be used. Simply specify separate load and run address for the `.econst` section in the user linker command file, and then add code to your project to copy the entire `.econst` section to RAM at runtime. For example:

```

/*****
* User's linker command file
*****/

SECTIONS
{
.econst:          LOAD = FLASH,  PAGE = 0
                  RUN  = RAM,    PAGE = 1
                  LOAD_START(_econst_loadstart),
                  LOAD_SIZE(_econst_loadsize),
                  RUN_START(_econst_runstart)
}

```

```

/*****
* User's C-source file
*****/

#include <string.h>

extern unsigned int econst_loadstart;
extern unsigned int econst_loadsize;
extern unsigned int econst_runstart;

void main(void)
{
/* Copy the .econst section */
    memcpy(&econst_runstart, &econst_loadstart, (Uint32)&econst_loadsize);
}

```

#### 4.6.1.2 DSP/BIOS Projects

Although the DSP/BIOS configuration tool allows the specification of different load and run addresses for the `.econst` section, it will not generate the code accessible labels that are needed to perform the memory copy. Therefore, the user must preemptively link the `.econst` section in the user linker command file before the DSP/BIOS generated linker command file is evaluated. The user linker command file would appear as follows:

```

/*****
* User's linker command file (DSP/BIOS Projects)
*****/

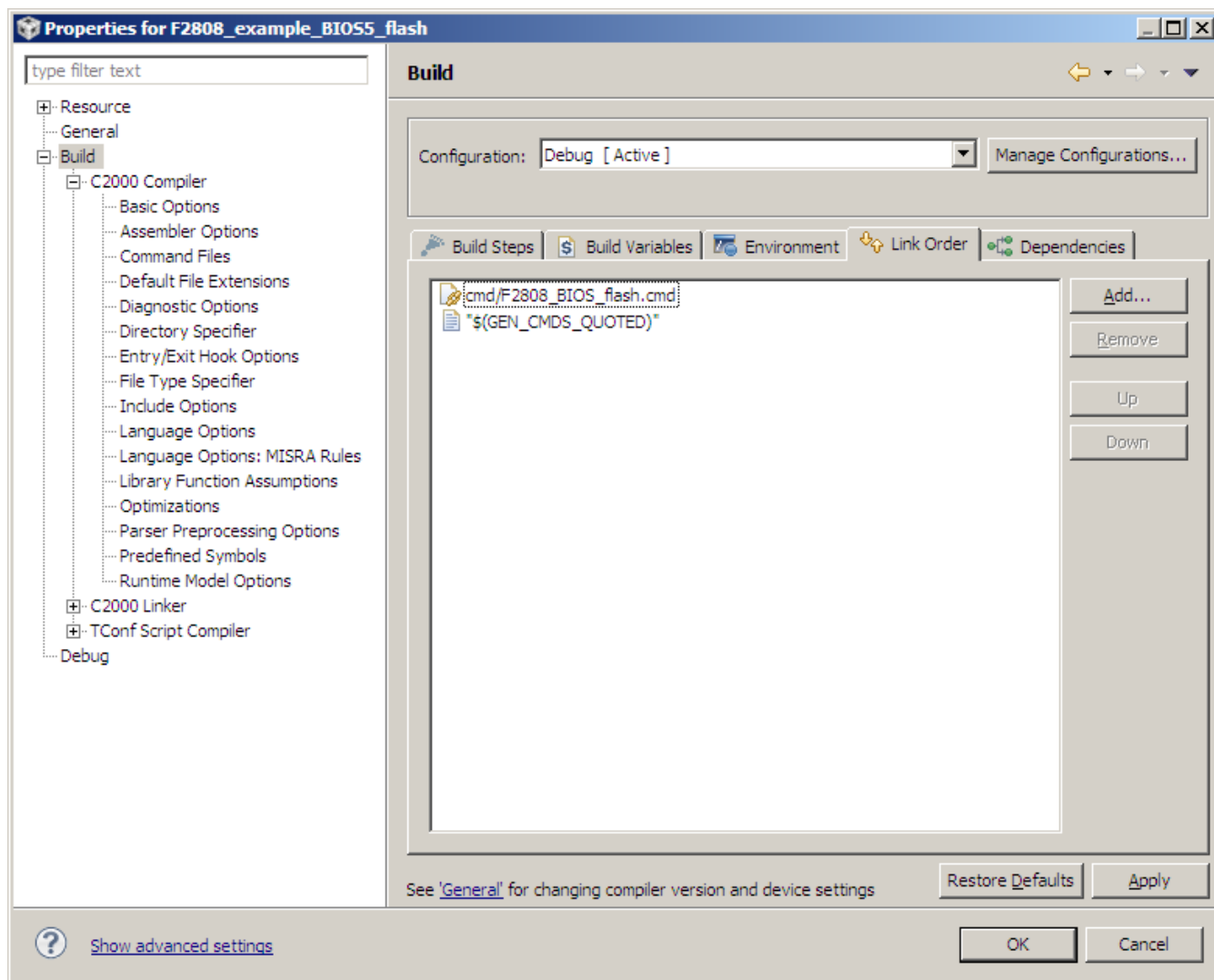
SECTIONS
{
/** Preemptively link the .econst section */
/* Must come before DSP/BIOS linker command file is evaluated */

.econst:          LOAD = FLASH,  PAGE = 0
                  RUN  = RAM,    PAGE = 1
                  LOAD_START(_econst_loadstart),
                  LOAD_SIZE(_econst_loadsize),
                  RUN_START(_econst_runstart)
}

```



To guarantee that the user linker command file is evaluated before the DSP/BIOS generated linker command file during the project build, one must specify the link order in CCS. To do this in CCS v5, go to Project → Properties, then select the Build category, Link Order tab. You can then specify the appropriate order for the linker command files in question by clicking on the 'Add...' button. Note that the DSP/BIOS generated linker command file will not be explicitly listed in the file selection list. Rather, you should select "\$(GEN\_CMDS\_QUOTED)" which means the DSP/BIOS generated .cmd file. Figure 2 shows an example of this, where *F2808\_BIOS\_flash.cmd* is the user linker command file and "\$(GEN\_CMDS\_QUOTED)" refers to the *F2808\_example\_BIOS\_flashcfg.cmd* file generated by DSP/BIOS.



**Figure 2. Specifying the Link Order In Code Composer Studio v5**

The `.econst` section can then be copied from its load address to its run address as follows:

```

/*****
* User's C-source file
*****/

#include <string.h>

extern unsigned int econst_loadstart;
extern unsigned int econst_loadsize;
extern unsigned int econst_runstart;

void main(void)
{
/* Copy the .econst section */
    memcpy(&econst_runstart, &econst_loadstart, (Uint32)&econst_loadsize);
}

```

#### 4.6.2 Method 2: Running a Specific Constant Array from RAM

##### (DSP/BIOS and non-DSP/BIOS projects)

This method involves selectively copying constants from flash to RAM at runtime. The procedure to accomplish this is similar to that of Method 1, except that only selected constants are placed in a named section and copied to RAM (rather than copying all constants to RAM).

Suppose for example that one wants to create a 5 word constant array called `table[]` to be run from RAM. A `DATA_SECTION` pragma is used to place `table[]` in a user defined section called `ramconsts`. The C-source file would appear as follows:

```

/*****
* User's C-source file
*****/

#pragma DATA_SECTION(table, "ramconsts")
const int table[5] = {1,2,3,4,5};

void main(void)
{
}

```

The section `ramconsts` is linked to load to flash but run from RAM using the user linker command file, and global symbols are generated to facilitate the memory copy. The user linker command file would appear as follows:

```

/*****
* User's linker command file
*****/

SECTIONS
{
/** User Defined Sections */
ramconsts:          LOAD = FLASH, PAGE = 0
                    RUN  = RAM,   PAGE = 1
                    LOAD_START(_ramconsts_loadstart),
                    LOAD_SIZE(_ramconsts_loadsize),
                    RUN_START(_ramconsts_runstart)
}

```

Finally, *table[]* must be copied from its load address to its run address at runtime:

```

/*****
* User's C-source file
*****/

#include <string.h>

extern unsigned int ramconsts_loadstart;
extern unsigned int ramconsts_loadsize;
extern unsigned int ramconsts_runstart;

void main(void)
{
/* Initialize the ramconsts section */
    memcpy(&ramconsts_runstart, &ramconsts_loadstart, (Uint32)&ramconsts_loadsize);
}

```

## 5 Programming the Code Security Module Passwords

### (DSP/BIOS and non-DSP/BIOS projects)

The CSM module on F28xxx devices provides protection against unwanted copying of your software. On current F28xxx devices, the entire flash, the OTP memory, and some of the 'L' SARAM blocks are secured by the CSM (see the device datasheet for device specific information). The flash configuration registers are secured as well. When secured, only code executing from secured memory can access data (read or write) in other secured memory. Code executing from unsecured memory cannot access data in secured memory. Detailed information on the CSM module can be found in references [9-14].

The CSM uses a 128-bit password comprised of 8 individual 16-bit words. On current F28xxx devices, these passwords are stored in the upper most 8 words of the flash (e.g., addresses 0x3F7FF8 through 0x3F7FFF on F281x, F280x, F2801x, F2804x, F2802x, F2803x, and F2806x devices, and addresses 0x33FFF8 through 0x33FFFF on F2823x and F2833x devices). During development, it is recommended that dummy passwords of 0xFFFF be used. When dummy passwords are used, only dummy reads of the password locations are needed to unsecure the CSM. Placing dummy passwords into the password locations is easy to do since 0xFFFF will be the state of these locations after the flash is erased during flash programming. Users need only avoid linking any sections to the password addresses in their code project, and the passwords will retain the 0xFFFF.

After development, one may want to use real passwords. In addition, to properly secure the CSM module on current F28xxx devices, values of 0x0000 must be programmed into the 118 flash addresses beginning 120 words prior to the start of the CSM passwords, e.g., addresses 0x3F7F80 through 0x3F7FF5 on F281x, F280x, F2801x, F2804x, F2802x, F2803x, and F2806x devices, and addresses 0x33FF80 through 0x33FFF5 on F2823x and F2833x devices (see references [1-7]). An easy way to accomplish both of these tasks is with a little simple assembly language programming. The following example assembly code file specifies the desired password values and places them in a named initialized section called *passwords*. It also creates a named initialized section called *csm\_rsvd* that contains all 0x0000 values and is of proper length to fit in the aforementioned 118 word address ranges. See reference [15] for more information on the assembly language directives used.

```

*****
* File: passwords.asm
*****

*****
* Dummy passwords of 0xFFFF are shown. The user can change these to
* desired values.
*
* CAUTION: Do not use 0x0000 for all 8 passwords or the CSM module will
* be permanently locked. See References [9-14] for more information.
*****

    .sect "passwords"
    .int  0xFFFF                ;PWL0 (LSW of 128-bit password)
    .int  0xFFFF                ;PWL1
    .int  0xFFFF                ;PWL2
    .int  0xFFFF                ;PWL3
    .int  0xFFFF                ;PWL4
    .int  0xFFFF                ;PWL5
    .int  0xFFFF                ;PWL6
    .int  0xFFFF                ;PWL7 (MSW of 128-bit password)
;-----
    .sect "csm_rsvd"
    .loop (3F7FF5h - 3F7F80h + 1)
    .int  0x0000
    .endloop
;-----

    .end                        ;end of file passwords.asm

```

Note that this example is showing dummy password values of 0xFFFF. Replace these values with your desired passwords.

#### **CAUTION:**

**Do not use 0x0000 for all 8 passwords. Doing so will permanently lock the CSM module! See references [9-14] for more information.**

The *passwords* and *csm\_rsvd* sections should be placed in memory with the user linker command file.

For non-DSP/BIOS projects, the user should define memories named (for example) *PASSWORDS* and *CSM\_RSVD* on PAGE 0 in the MEMORY portion of the user linker command file. The sections *passwords* and *csm\_rsvd* can then be linked to these memories. The following example applies to F281x, F280x, F2801x, F2804x, F2802x, F2803x, and F2806x devices. For other devices, consult the device datasheet to confirm the addresses of the password and CSM reserved locations.

```

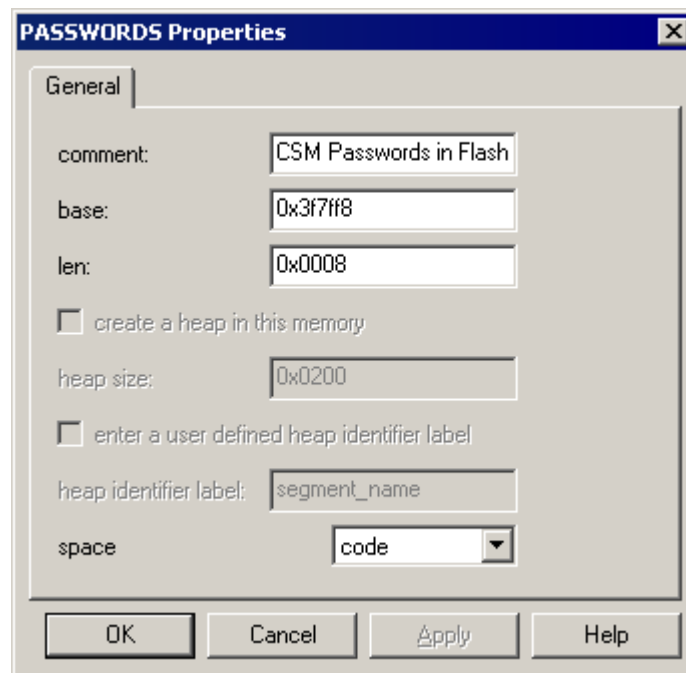
/*****
* User's user linker command file (non-DSP/BIOS Projects)
*****/

MEMORY
{
PAGE 0:      /* Program Memory */
    CSM_RSVD   : origin = 0x3F7F80, length = 0x000076
    PASSWORDS  : origin = 0x3F7FF8, length = 0x000008
PAGE 1:      /* Data Memory */
}

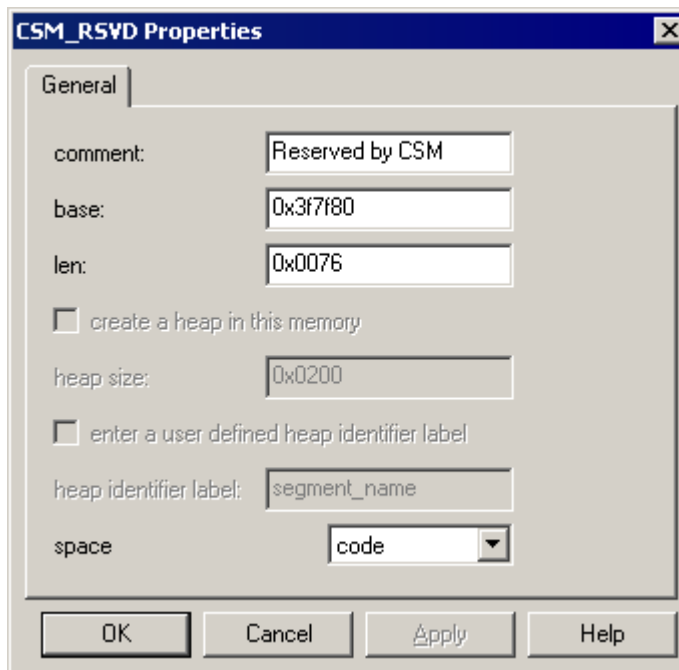
SECTIONS
{
/*** Code Security Password Locations ***/
passwords:    > PASSWORDS,      PAGE = 0
csm_rsvd:     > CSM_RSVD,       PAGE = 0
}

```

For DSP/BIOS projects, the user should define the memories named (for example) *PASSWORDS* and *CSM\_RSVD* using the memory section manager of the DSP/BIOS configuration tool. The two figures that follow show the DSP/BIOS memory section manager properties for these memories on F281x, F280x, F2801x, F2804x, F2802x, F2803x, and F2806x devices. As always, consult the device datasheet to confirm the correct addresses and lengths, or for memory map information of other F28xx devices.



**Figure 3. DSP/BIOS MEM Properties for CSM Password Locations**



**Figure 4. DSP/BIOS MEM Properties for CSM Reserved Locations**

The sections *passwords* and *csm\_rsvd* can then be linked to these memories in the user linker command file. For DSP/BIOS projects, the user linker command file would appear as:

```

/*****
* User's linker command file (DSP/BIOS Projects)
*****/

SECTIONS
{
  /*** Code Security Password Locations ***/
  passwords:      > PASSWORDS,      PAGE = 0
  csm_rsvd:        > CSM_RSVD,       PAGE = 0
}

```

## 6 Executing Your Code from Flash after a DSP Reset

### (DSP/BIOS and non-DSP/BIOS projects)

F28xxx devices contain a ROM bootloader that can transfer code execution to the flash after a device reset. The ROM bootloader is detailed in references [14, 16 - 20]. When the boot mode selection pins are configured for "Jump to Flash" mode, the ROM bootloader will branch to the instruction located at address 0x3F7FF6 in the flash (this is for F281x, F280x, F2801x, F2804x, F2802x, F2803x, and F2806x devices - see device datasheet for your specific device). The user should place an instruction that branches to the beginning of their code at this address. Recall that the CSM passwords begin at address 0x3F7FF8 (again, for F281x, F280x, F2801x, F2804x, F2802x, F2803x, and F2806x), so that exactly 2 words are available to hold the branch instruction. Not coincidentally, a long branch (LB in assembly code) occupies 2 words.

In general, the branch instruction will branch to the start of the C-environment initialization routine located in the C-compiler runtime support library. The entry symbol for this routine is `_c_int00`. No C code can be executed until this setup routine is run. Alternately, there is sometimes a need to execute a small amount of assembly code prior to starting your C application (for example, to disable the watchdog timer peripheral). In this case, the branch instruction should branch to the start of your assembly code. Regardless, there is a need to properly locate this branch instruction in the flash. The easiest way to do this is with assembly code. The following example creates a named initialized section called *codestart* that contains a long branch to the C-environment setup routine. The *codestart* section should be placed in memory with the user linker command file.

```
*****
* CodeStartBranch.asm
*****

    .ref _c_int00

    .sect "codestart"
    LB _c_int00                ;branch to start of code

    .end                      ;end of file CodeStartBranch.asm
```

For non-DSP/BIOS projects, the user should define a memory named (for example) *BEGIN\_FLASH* on PAGE 0 in the MEMORY portion of the user linker command file. The section *codestart* can then be linked to this memory. The following example applies to F281x, F280x, F2801x, F2804x, F2802x, F2803x, and F2806x devices. For other F28xxx devices, consult the device datasheet to confirm the boot to flash target address.



```

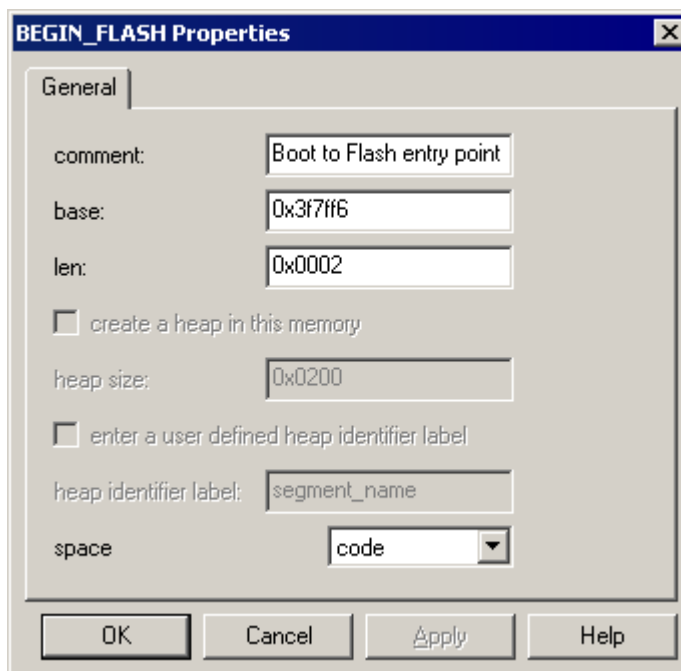
/*****
* User's linker command file (non-DSP/BIOS Projects)
*****/

MEMORY
{
PAGE 0:      /* Program Memory */
    BEGIN_FLASH : origin = 0x3F7FF6, length = 0x000002
PAGE 1:      /* Data Memory */
}

SECTIONS
{
/** Jump to Flash boot mode entry point ***/
codestart:   > BEGIN_FLASH, PAGE = 0
}

```

For DSP/BIOS projects, the user should define the memory named *BEGIN\_FLASH* (for example) using the memory section manager of the DSP/BIOS configuration tool. Figure 5 shows the memory section manager properties for this memory on F281x, F280x, F2801x, F2802x, F2803x, F2804x, and F2806x devices. For other devices, consult the datasheet to confirm the boot to flash target address.



**Figure 5. DSP/BIOS MEM Properties for Jump to Flash Entry Point**

The section *codestart* can then be linked to this memory in the user linker command file. For DSP/BIOS projects, the linker command file would appear as:

```
/* *****  
 * User's linker command file (DSP/BIOS projects)  
 * ***** */  
  
SECTIONS  
{  
  /** Jump to Flash boot mode entry point ***/  
  codestart:      > BEGIN_FLASH, PAGE = 0  
}
```

## 7 Disabling the Watchdog Timer During C-Environment Boot

### (DSP/BIOS and non-DSP/BIOS projects)

The C-environment initialization function in the C compiler runtime support library, `_c_int00`, performs the initialization of global and static variables. This involves a data copy from the `.cinit` section (located in on-chip flash memory) to the `.ebss` section (located in RAM) for each initialized global variable. For example, when a global variable is declared in source code as:

```
int x=5;
```

the "5" is placed into the initialized section `.cinit`, whereas space is reserved in the `.ebss` section for the symbol "x." The `_c_int00` routine then copies the "5" to location "x" at runtime. When a large number of initialized global and static variables are present in the software, the watchdog timer can timeout before the C-environment boot routine can finish and call `main()` (where the watchdog can be either configured and serviced, or disabled). This problem may not manifest itself during code development in RAM since the data copy from a `.cinit` section linked to RAM will occur at a fast pace. However, when the `.cinit` section is linked to internal flash, copying each data word will take multiple cycles since the internal flash memory defaults to the maximum number of wait-states (wait-states are not configured until the user code reaches `main()`). In addition, the code performing the data copying is executing from flash, which further increases the time needed to complete the data copy (the code fetches and data reads must share access to the flash). Combined with the fact that the watchdog timeout period defaults to its minimum possible value, a watchdog timeout becomes a real possibility.

You can detect the presence of this problem in your system by using the CCS debugger. Set a breakpoint at the start of `main()`, and also set a breakpoint at the start of `_c_int00`. Reset the processor, and then run. You should hit the breakpoint at `_c_int00`. If you do not, you have a bootmode configuration problem. If you get to `_c_int00`, run again. This time you should get to the breakpoint in `main()`. If you do not, the watchdog is timing out before you get there.

The easiest method for correcting the watchdog timeout problem is to disable the watchdog before starting the C-environment boot routine. The watchdog can later be re-enabled after reaching `main()` and starting your normal code execution flow. The watchdog is disabled by setting the WDDIS bit to a 1 in the WDCR register. To disable the watchdog before the boot routine, assembly code must be used (since the C environment is not yet setup). In Section 6, the `codestart` assembly code section implemented a branch instruction that jumped to the C-environment initialization routine, `_c_int00`. To disable the watchdog, this branch should instead jump to watchdog disabling code, which can then branch to the `_c_int00` routine. The following code example performs these tasks:

```

*****
* File: CodeStartBranch.asm
* Devices: TMS320F28xxx
* Author: David M. Alter, Texas Instruments Inc.
* History: 02/11/05 - original (D. Alter)
*****

WD_DISABLE    .set    1        ;set to 1 to disable WD, else set to 0

                .ref _c_int00

*****
* Function: codestart section
* Description: Branch to code starting point
*****
                .sect "codestart"
                .if WD_DISABLE == 1
                    LB wd_disable        ;Branch to watchdog disable code
                .else
                    LB _c_int00          ;Branch to start of boot.asm in RTS library
                .endif
;end codestart section

*****
* Function: wd_disable
* Description: Disables the watchdog timer
*****
                .if WD_DISABLE == 1

                .text
wd_disable:
                EALLOW                ;Enable EALLOW protected register access
                MOVZ DP, #7029h>>6    ;Set data page for WDCR register
                MOV @7029h, #0068h     ;Set WDDIS bit in WDCR to disable WD
                EDIS                   ;Disable EALLOW protected register access
                LB _c_int00            ;Branch to start of boot.asm in RTS library

                .endif

;end wd_disable
*****

                .end                ; end of file CodeStartBranch.asm

```

## 8 C-Code Examples

### 8.1 General Overview

A code download containing CCS v5 code projects for the superset device in each of the F281x, F280x, F2802x, F2803x, F2806x, and F2833x sub-families accompanies this application report (projects for the older CCS v4 are also provided for convenience). With the exception of the F2802x and F2803x, each device type has four distinct projects:

- F28xxx\_example\_nonBIOS\_ram.pjt - non-DSP/BIOS project that runs from on-chip RAM
- F28xxx\_example\_nonBIOS\_flash.pjt - non-DSP/BIOS project that runs from on-chip Flash
- F28xxx\_example\_BIOS\_ram.pjt - DSP/BIOS project that runs from on-chip RAM
- F28xxx\_example\_BIOS\_flash.pjt - DSP/BIOS project that runs from on-chip Flash

The F2802x and F2803x examples do not include the F28xxx\_example\_BIOS\_ram.pjt since from a practical perspective there is insufficient RAM on these devices to support DSP/BIOS without utilizing the flash memory to hold the bulk of the code.

These are just examples, and have only been tested briefly. No guarantee is made about their suitability for application usage. The examples were built and tested using the following development tool versions:

CCS v5.1.0, Code Generation Tools v6.0.2, DSP/BIOS v5.41.11.38

(the provided CCS v4.2.4 projects were done with the same code gen and DSP/BIOS as above).

Although the focus of this report is running code from flash, the RAM examples are provided for completeness and can be useful during the early stages of development work.

The projects were developed on the eZdspF2812, eZdspF2808, and eZdspF28335 development boards, the F2808, F28335, F28027, F28035, and F28069 Experimenter's Kits, and the F28027 and F28069 'Piccolo' Control Sticks. However, they will also run on other F28xxx board as follows:

**F281x examples:** These will run on any F281x board as they run entirely from internal memory and use only the flash memory common to all three devices. If running on a different board, be aware that the code configures the GPIOA0/PWM1 and GPIOF14/XF\_XPLLDIS\* pins as outputs. Also note that the code does configure the external memory interface on the F2812 as part of the DSP initialization process. Since most of the external memory interface does not exist on F2810 and F2811 devices (exception is the XCLKOUT pin), this initialization is not needed on these two devices (although it is harmless).

**F280x examples:** These will run on any F2808 board. They can also be adapted to run on other F280x, F2801x, and F2804x boards by adjusting the memory definitions (RAM and Flash) in the .cmd file for non-DSP/BIOS projects, or the .tcf file for DSP/BIOS projects. The PLL setting may also need to be adjusted depending on the crystal or oscillator used on the board and the operating frequency of the device. If running on a different board, the user should be aware that the code configures the GPIO0/ePWM1A and GPIO34 pins as outputs.

**F2833x examples:** These will run on any F28335 board. They can also be adapted to run on other F2833x or F2823x boards by adjusting the memory definitions (RAM and Flash) in the .cmd file for non-DSP/BIOS projects, or the .tcf file for DSP/BIOS projects. The PLL setting may also need to be adjusted depending on the crystal or oscillator used on the board and the operating frequency of the device. Also, for F2823x devices, you should change the project build options in CCS v5 to disable floating point support (go to Project → Properties, select the Build → C2000 Compiler → Runtime Model Options category, and change the 'Specify floating point support' box to blank). If running on a different board, the user should be aware that the code configures the GPIO0/ePWM1A, GPIO32, and GPIO34 pins as outputs.

**F2802x examples:** These will run on any F28027 board. They can also be adapted to run on other F2802x boards by adjusting the memory definitions (RAM and Flash) in the .cmd file for non-DSP/BIOS projects, or the .tcf file for DSP/BIOS projects. The PLL setting may also need to be adjusted depending on the operating frequency of the device. If running on a different board, the user should be aware that the code configures the GPIO0/ePWM1A and GPIO34 pins as outputs.

**F2803x examples:** These will run on any F28035 board. They can also be adapted to run on other F2803x boards by adjusting the memory definitions (RAM and Flash) in the .cmd file for non-DSP/BIOS projects, or the .tcf file for DSP/BIOS projects. If running on a different board, the user should be aware that the code configures the GPIO0/ePWM1A and GPIO34 pins as outputs.

**F2806x examples:** These will run on any F28069 board. They can also be adapted to run on other F2806x boards by adjusting the memory definitions (RAM and Flash) in the .cmd file for non-DSP/BIOS projects, or the .tcf file for DSP/BIOS projects. If running on a different board, the user should be aware that the code configures the GPIO0/ePWM1A and GPIO34 pins as outputs.

The source code uses versions of the C2000 peripheral header files for accessing peripheral registers on the F28xxx as follows:

- DSP281x Peripheral Header File structures v1.20
- DSP280x Peripheral Header File structures v1.70
- DSP2833x Peripheral Header File structures v1.32
- DSP2802x Peripheral Header File structures v1.29
- DSP2803x Peripheral Header File structures v1.25<sup>1</sup>
- F2806x Peripheral Header File structures v1.15

All needed files from the header file packages are included here (see references [23-29]). However, the user is encouraged to download the complete header file package for additional information. These are available directly on the TI website, <http://www.ti.com> for the older devices. For the newest devices, they are available via the ControlSuite tool, installable from <http://www.ti.com/tool/controlsuite>.

---

<sup>1</sup> DSP2803x v1.25 contains an error in the file DSP2803x\_Headers\_BIOS.cmd in that the SECTIONS specifications for the HRCap1RegsFile and HRCap2RegsFile are missing. This has been corrected in the files included with this appnote, and affects the F28035\_example\_BIOS5\_flash projects for CCSv5 and CCSv4. The error will be corrected in a future release of the DSP2803x Peripheral Header Files.

Each of the code projects perform the same functions:

- Illustrates F28xxx device initialization. The PLL is configured for maximum clock speed allowed for each device.
- Enables the real-time emulation mode of Code Composer Studio.
- Toggles the GPIOF14 pin on the F2812, the GPIO34 pin on F2808, F28027, F28035, and F28069, and the GPIO32 and GPIO34 pins on the F28335. This blinks the LED on the development board (for F28335, only one GPIO is connected to an LED, depending on which board is in use). In non-DSP/BIOS projects, this is done in the ADCINT ISR. In DSP/BIOS projects, a periodic function is used.
- Configures the ADC to sample the ADCINA0 channel. On F2812, F2808, F28335, and F28069 devices, this is done at a 50 kHz rate. On the slower 60 MHz F28027 and F28035 devices, this is done at a 25 kHz rate. This is due to CPU loading constraints in the DSP/BIOS examples, which illustrates why you should not put a high-speed interrupt under DSP/BIOS control as was done in these examples (i.e., the ADC SWI)! Instead, execute your high frequency interrupt routines directly in the HWI. DSP/BIOS can still manage the overall system and lower frequency ISRs.
- Services the ADC interrupt. The ADC result is placed in a circular buffer of length 50 words.
- Sends out 2 kHz symmetric PWM on either the PWM1 pin (for F281x), or the ePWM1A signal mapped to the GPIO0 pin (for F2808, F28335, F28027, F28035, and F28069).
- Configures the capture unit #1. On F2808, F28335, F28027, F28035, and F28069 devices, the eCAP1 signal is mapped to the GPIO5 pin.
- Services the capture #1 interrupt. Reads the capture result and computes the pulse width.

## **8.2 Directory Structure**

Each code project is completely self-contained in terms of all needed files (with the exception of the C-compiler runtime support (RTS) library which is taken from the folder of the code generation tools being used by the CCS project). Table 3 provides a description of the directory structure for individual CCS projects.

**Table 3. CCS Example Code Directory Descriptions**

<b>File Directory</b>	<b>Contents</b>
<project_root>	Contains the CCS created project files: .ccsproject, .cdtbuild, .cdtproject, .project, and DSP/BIOS .tcf.
<project_root>\.settings	Contains CCS created project setting files
<project_root>\cmd	Contains the user linker command file (.cmd file)
<project_root>\DSP28xxx_headers\cmd or <project_root>\F28xxx_headers\cmd	Contains the needed linker command file from the Peripheral Header File structures for the targeted device.
<project_root>\DSP28xxx_headers\include or <project_root>\F28xxx_headers\include	Contains the needed include files from the Peripheral Header File structures for the targeted device.
<project_root>\include	Contains include files (.h files)
<project_root>\src	Contains source code files (.c and .asm files)

### 8.3 Additional Information

1) After building a project, the .out file will be located in the <project\_root>\Debug directory.

2a) If using the RAM examples, your board should be configured for "Jump to H0 SARAM" (F2812) or "Jump to M0 SARAM" (F2808, F28027, F28035, F28069, F28335) boot mode. Check the reference manual for your board to confirm any needed jumper settings, and also see the Boot ROM user's guide for your device (references [14, 16-20]). A summary for some development boards is given below. Check the board jumpers/dip-switch to be:

**eZdspF2812:** JP1 2-3 (MP/MC\*)

JP9 1-2 (PLL)

JP7 2-3 (boot mode selection)

JP8 2-3 (boot mode selection)

JP11 1-2 (boot mode selection)

JP12 2-3 (boot mode selection)

**eZdspF2808:** DIP SW1: 1 = ON

2 = OFF

3 = ON

**eZdspF28335:** DIP SW1: 1 = ON

2 = ON

3 = OFF

4 = ON



**F2808 Experimenter's Kit:** Current versions of this board are hardwired for jump-to-flash bootmode. The debugger can be used to set the PC to begin execution from the code entry point (e.g. `_c_int00`). In CCS v5, Run → Restart will set the PC to this entry point.

**F28335 Experimenter's Kit:** Current versions of this board are hardwired for jump-to-flash bootmode. The debugger can be used to set the PC to begin execution from the code entry point (e.g. `_c_int00`). In CCS v5, Run → Restart will set the PC to this entry point.

**F28027 Experimenter's Kit or ControlStick:** When the emulator is connected to the F28027, the debugger is used to select the boot mode. Check the Scripts menu in CCS v5 for boot mode selection options.

**F28035 Experimenter's Kit:** When the emulator is connected to the F28035, the debugger is used to select the boot mode. Check the Scripts menu in CCS v5 for boot mode selection options.

**F28069 Experimenter's Kit or ControlStick:** When the emulator is connected to the F28069, the debugger is used to select the boot mode. Check the Scripts menu in CCS v5 for boot mode selection options.

If the above methods do not seem to be working, check the reference manual for your board to confirm any needed jumper settings, and also see the Boot ROM user's guide for your device (references [14, 16-20]).

2b) If using the FLASH examples, your board should be configured for "Jump to Flash" boot mode. Check the reference manual for your board to confirm any needed jumper settings, and also see the Boot ROM user's guide for your device (references [14, 16-20]). A summary for some development boards is given below. Check the board jumpers/dip-switch to be:

**eZdspF2812:** JP1 2-3 (MP/MC\*)

JP9 1-2 (PLL)

JP7 1-2 (boot mode selection)

JP8 don't care (boot mode selection)

JP11 don't care (boot mode selection)

JP12 don't care (boot mode selection)

**eZdspF2808:** DIP SW1: 1 = OFF

2 = OFF

3 = OFF

**eZdspF28335:** DIP SW1: 1 = OFF

2 = OFF

3 = OFF

4 = OFF

**F2808 Experimenter's Kit:** This board is hardwired jump-to-flash boot mode.

**F28335 Experimenter's Kit:** This board defaults to jump-to-flash boot mode.

**F28027 Experimenter's Kit or ControlStick:** When the emulator is connected, the debugger is used to select the boot mode. Check the Scripts menu in CCS v5 for selection options. When the emulator is disconnected, the board will boot in jump-to-flash mode provided the OTP\_KEY and OTP\_BMODE locations in the OTP have not been otherwise programmed, and on the Experimenter's Kit only:

DIP SW1: 1 = ON

2 = ON

**F28035 Experimenter's Kit or ControlStick:** When the emulator is connected, the debugger is used to select the boot mode. Check the Scripts menu in CCS v5 for boot mode selection options. When the emulator is disconnected, the board will boot in jump-to-flash mode provided the OTP\_KEY and OTP\_BMODE locations in the OTP have not been otherwise programmed, and on the Experimenter's Kit only:

DIP SW2: 1 = ON

2 = ON

**F28069 Experimenter's Kit or ControlStick:** When the emulator is connected, the debugger is used to select the boot mode. Check the Scripts menu in CCS v5 for boot mode selection options. When the emulator is disconnected, the board will boot in jump-to-flash mode provided the OTP\_KEY and OTP\_BMODE locations in the OTP have not been otherwise programmed, and on the Experimenter's Kit only:

DIP SW2: 1 = ON

2 = ON

If the above methods do not seem to be working, check the reference manual for your board to confirm any needed jumper settings, and also see the Boot ROM user's guide for your device (references [14, 16-20]).

3) There has not been too much attention given to where everything is linked. The goal in writing these example projects was to simply get them working. If these projects are used as a starting point for code development, the linking may need to be tuned to get better performance (e.g., to avoid memory block access contention, or to better manage memory block utilization).

4) For non-DSP/BIOS projects, a complete set of interrupt service routines are defined in the file *DefaultIsr\_nonBIOS.c*. Each interrupt is executed directly in its hardware ISR. However, with the exception of the ADCINT and ECAP1INT (or CAPINT1 on F2812), each ISR actually executes an ESTOP0 instruction (emulation stop) to trap spurious interrupts during debug, followed by an endless loop. In production code, you would want to vector unused interrupts to some sort of error handling routine of your own design (as opposed to just trapping the code). Note that each ISR is using the "interrupt" keyword which tells the compiler to perform a context save/restore upon function entry/exit.

5) For DSP/BIOS projects, a complete set of (hardware) interrupt service routines are defined in the file *DefaultIsr\_BIOS.c*. Each ISR can be hooked to the desired interrupt using the HWI manager in the DSP/BIOS configuration tool. As is, the code examples only assign the two ISRs in use, specifically ADCINT1 and ECAP1INT. Also, the DSP/BIOS Interrupt Dispatcher is being used to handle the context save/restore, which is why the ISRs are not using the "interrupt" keyword (as in the non-DSP/BIOS case). In these examples, the ECAP1INT ISR (or CAPINT1 ISR for F2812) is performed directly in the *DefaultIsr\_BIOS.c* file (as an example of reducing latency), whereas the ADC interrupt function in *DefaultIsr\_BIOS.c* posts a SWI to perform the ADC routine. These are just examples. Note that the ECAP1INT (and CAPINT1) ISRs are using the DSP/BIOS dispatcher to perform context save/restore (as selected in the HWI manager of the configuration tool). If absolute minimum latency is required (for some time critical ISR), one could disable the interrupt dispatcher for that interrupt, and add the "interrupt" keyword to the ISR function declaration. Note that doing so will preclude the user for utilizing any DSP/BIOS functionality in that ISR. Finally, the HWI manager in the DSP/BIOS Configuration tool defaults all unused interrupts to a routine called *HWI\_unused()*. This routine is essentially and code trap using an endless loop. For production code, you should vector all unused interrupts to some sort of error handling routine of your own design.

## References

1. TMS320F2810, TMS320F2811, TMS320F2812, TMS320C2810, TMS320C2811, TMS320C2812 Digital Signal Processors Data Manual (SPRS174)
2. TMS320F2809, TMS320F2808, TMS320F2806, TMS320F2802, TMS320F2801, TMS320C2802, TMS320C2801, TMS320F2801x DSPs Data Manual (SPRS230)
3. TMS320F28044 Digital Signal Processor Data Manual (SPRS357)
4. TMS320F28335, TMS320F28334, TMS320F28332, TMS320F28235, TMS320F28234, TMS320F28232 Digital Signal Controllers Data Manual (SPRS439)
5. TMS320F28020, TMS320F28021, TMS320F28022, TMS320F28023, TMS320F28026, TMS320F28027 Piccolo Microcontrollers Data Manual (SPRS523)
6. TMS320F28030, TMS320F28031, TMS320F28032, TMS320F28033, TMS320F28034, TMS320F28035 Piccolo Microcontrollers Data Manual (SPRS584)
7. TMS320F28062, TMS320F28063, TMS320F28064, TMS320F28065, TMS320F28066, TMS320F28067, TMS320F28068, TMS320F28069 Piccolo Microcontrollers Data Manual (SPRS698)
8. TMS320C28x Optimizing C/C++ Compiler User's Guide (SPRU514)
9. TMS320x281x DSP System Control and Interrupts Reference Guide (SPRU078)
10. TMS320x280x, 2801x, 2804x DSP System Control and Interrupts Reference Guide (SPRU712)
11. TMS320x2833x System Control and Interrupts Reference Guide (SPRUFB0)
12. TMS320x2802x System Control and Interrupts Reference Guide (SPRUFN3)
13. TMS320x2803x System Control and Interrupts Reference Guide (SPRUGL8)
14. TMS320x2806x Piccolo Technical Reference Manual (SPRUH18)
15. TMS320C28x Assembly Language Tools User's Guide (SPRU513)
16. TMS320x281x DSP Boot ROM Reference Guide (SPRU095)
17. TMS320x280x, 2801x, 2804x Boot ROM Reference Guide (SPRU722)
18. TMS320x2833x, 2832x Boot ROM Reference Guide (SPRU963)
19. TMS320x2802x Piccolo Boot ROM Reference Guide (SPRUFN6)
20. TMS320x2803x Piccolo Boot ROM Reference Guide (SPRUGO0)
21. TMS320C28x CPU and Instruction Set Reference Guide (SPRU430)
22. TMS320C28x Floating Point Unit and Instruction Set Reference Guide (SPRUE02)
23. F281x C/C++ Header Files and Peripheral Examples (SPRC097)
24. F280x C/C++ Header Files and Peripheral Examples (SPRC191)
25. F2804x C/C++ Header Files and Peripheral Examples (SPRC324)
26. F2833x/C2823x C/C++ Header Files and Peripheral Examples (SPRC530)
27. F2802x C/C++ Header Files and Peripheral Examples (SPRC832)
28. F2803x C/C++ Header Files and Peripheral Examples (SPRC892)
29. F2806x C/C++ Header Files and Peripheral Examples (available in ControlSuite)

## Revision History

Revision	Date	Who	Description of Major Changes from Previous Version
SPRA958K	Jan 10, 2012	D. Alter	<ul style="list-style-type: none"> <li>- CCS v5.1 support and code examples added.</li> <li>- Updated all code to use the latest Peripheral Header files for each device.</li> <li>- All code tested with CCS v5.1.0, C-compiler v6.0.2, and DSP/BIOS v5.41.11.38.</li> <li>- Removed the ADC reset from InitAdc() function. This was not needed, and clears the ADC calibration constants on those devices using them, requiring a re-run of AdcCal() or DeviceCal(), depending on the device.</li> </ul>

## IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of TI products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by TI. Further, Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any failure to meet such requirements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

### Products

Audio	<a href="http://www.ti.com/audio">www.ti.com/audio</a>
Amplifiers	<a href="http://amplifier.ti.com">amplifier.ti.com</a>
Data Converters	<a href="http://dataconverter.ti.com">dataconverter.ti.com</a>
DLP® Products	<a href="http://www.dlp.com">www.dlp.com</a>
DSP	<a href="http://dsp.ti.com">dsp.ti.com</a>
Clocks and Timers	<a href="http://www.ti.com/clocks">www.ti.com/clocks</a>
Interface	<a href="http://interface.ti.com">interface.ti.com</a>
Logic	<a href="http://logic.ti.com">logic.ti.com</a>
Power Mgmt	<a href="http://power.ti.com">power.ti.com</a>
Microcontrollers	<a href="http://microcontroller.ti.com">microcontroller.ti.com</a>
RFID	<a href="http://www.ti-rfid.com">www.ti-rfid.com</a>
OMAP Mobile Processors	<a href="http://www.ti.com/omap">www.ti.com/omap</a>
Wireless Connectivity	<a href="http://www.ti.com/wirelessconnectivity">www.ti.com/wirelessconnectivity</a>

### Applications

Automotive and Transportation	<a href="http://www.ti.com/automotive">www.ti.com/automotive</a>
Communications and Telecom	<a href="http://www.ti.com/communications">www.ti.com/communications</a>
Computers and Peripherals	<a href="http://www.ti.com/computers">www.ti.com/computers</a>
Consumer Electronics	<a href="http://www.ti.com/consumer-apps">www.ti.com/consumer-apps</a>
Energy and Lighting	<a href="http://www.ti.com/energy">www.ti.com/energy</a>
Industrial	<a href="http://www.ti.com/industrial">www.ti.com/industrial</a>
Medical	<a href="http://www.ti.com/medical">www.ti.com/medical</a>
Security	<a href="http://www.ti.com/security">www.ti.com/security</a>
Space, Avionics and Defense	<a href="http://www.ti.com/space-avionics-defense">www.ti.com/space-avionics-defense</a>
Video and Imaging	<a href="http://www.ti.com/video">www.ti.com/video</a>

TI E2E Community Home Page

[e2e.ti.com](http://e2e.ti.com)

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265  
Copyright © 2012, Texas Instruments Incorporated